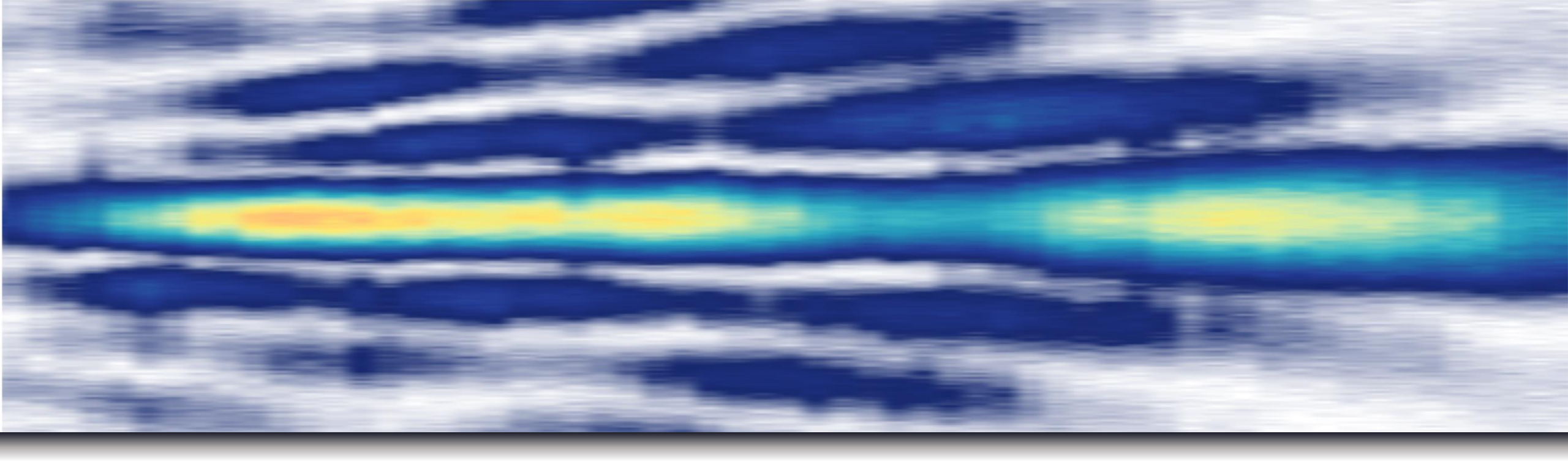

Laser Pulse Tailoring For HOFI Waveguide Generation

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DESY.

European Advanced Accelerator Conference
Hotel Hermitage, Elba
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DESY.

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MPL – Plasma Accelerator and Laser Group at DESY

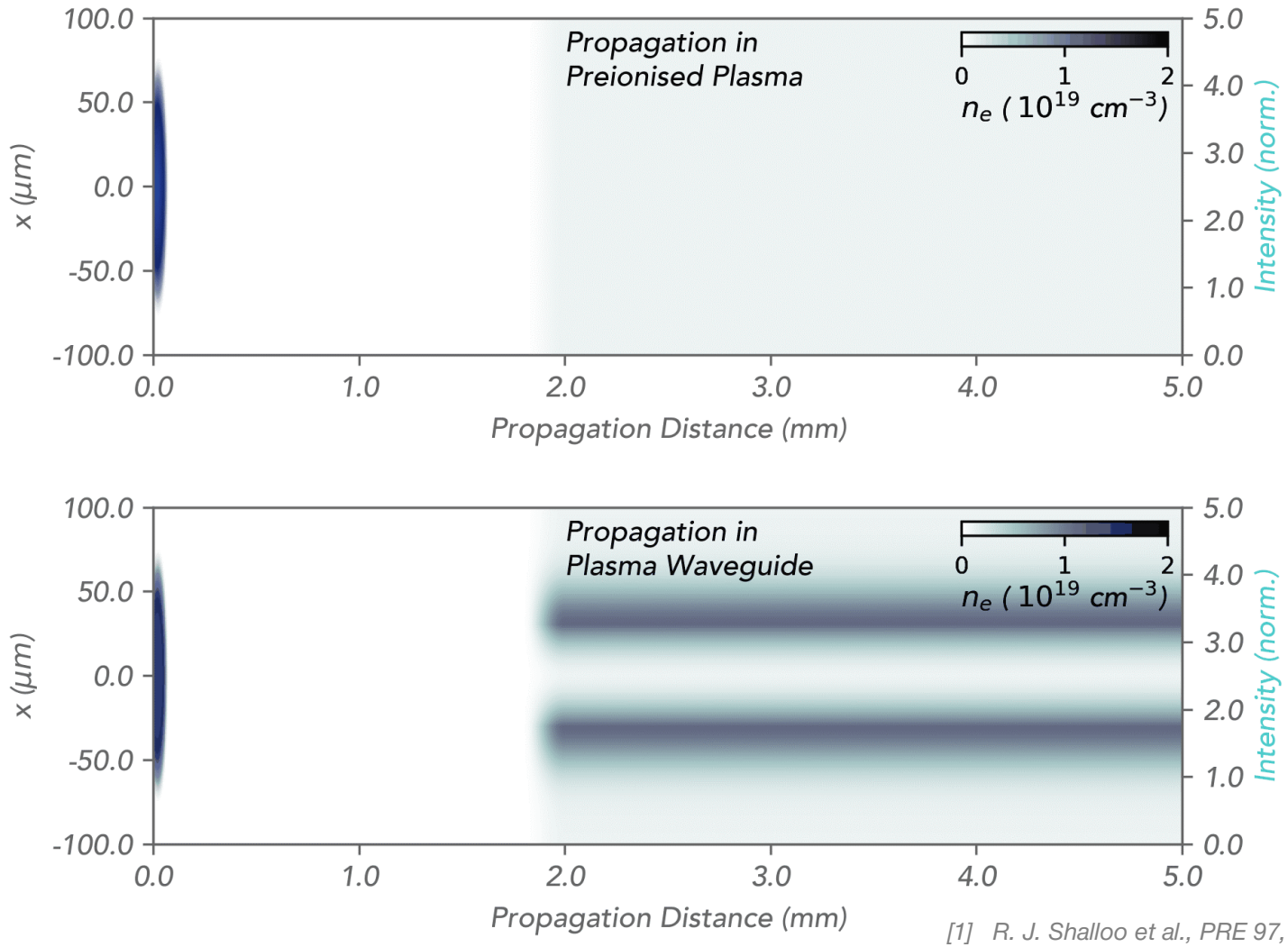
Fig: Marta Mayer (DESY)

See our webpage at plasma.desy.de
For a full list of teams and activities

DESY.

Hydrodynamic Optical Field Ionized (HOFI) plasma waveguides

Boosting energy of LPA electron beams



Why use HOFI [1]:

- Essential for Multi-GeV LPAs
- Extends high-intensity region of drive beam
- Freestanding and resistent to damage

Requires auxiliary beam and special optics

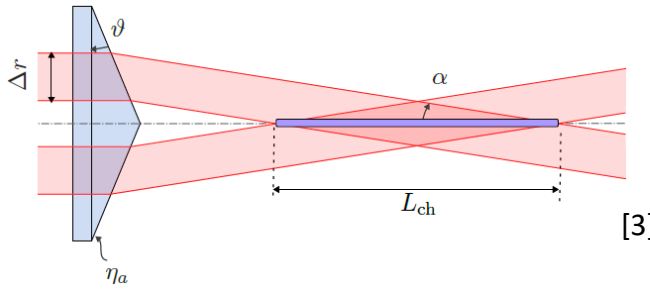
[1] R. J. Shalloo et al., PRE 97, 053203 (2018)
[2] R. J. Shalloo et al., PRAB 22, 041302 (2019)
[3] C. G. Durfee & H. M. Milchberg, PRL 71, 2409 (1993)
[4] T. R. Clark & H. M. Milchberg, PRL 78, 2373 (1997)
[5] N. Lemos et al., Phys. Plasmas 20, 063102 (2013)
[6] A. Morozov et al., Phys. Plasmas 25, 053110 (2018)
[7] A. Picklsey et al., PRE 102, 053201 (2020)

Existing optics for elongating focal region

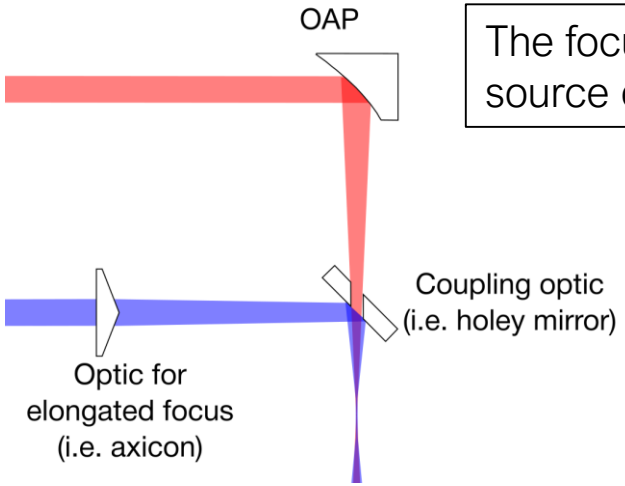
Focusing and elongation in one step

Axioptics: Radially varying focusing forms elongated focal region

- Axicon [1] ,
- Axilens [2] ,
- Axiparabola [5]



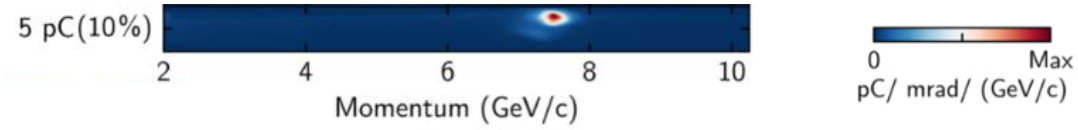
[3]



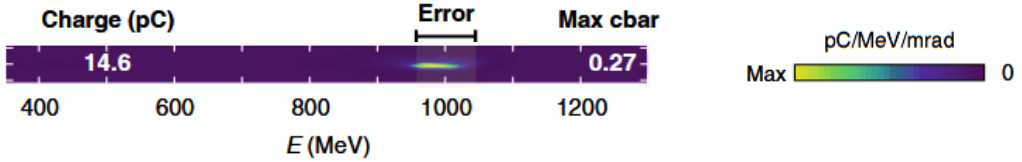
The focusing optic is a large source of focus jitter

Widely used for electron acceleration in HOFI waveguides

Electron spectrum from **axicon** generated waveguide (adapted from [4]):



Electron spectrum from **axiparabola** generated waveguide (adapted from [6]) :



Drawbacks:

- Custom fixed optics
- Relative pointing between beams [7]

[1] John H. McLeod, J. Opt. Soc. Am. 44, 592-597 (1954)
[2] N. Davidson, A. A. Friesem, and E. Hasman, Opt. Lett. 16, 523 (1991).
[3] Rob Shalloo, PhD Thesis, University of Oxford (2018)
[4] Picksley et al., Phys. Rev. Lett. 133, 255001 (2024)
[5] K. Oubrerie, I. A. Andriyash, R. Lahaye, et al., J. Opt. 24, 045503 (2022)
[6] Oubrerie, K., Leblanc, A., Kononenko, O. et al., Light Sci Appl 11, 180 (2022)
[7] Picksley et al., Phys. Rev. Lett. 131, 245001 (2023)
[8] B. Miao et al., PRX 12, 031038 (2022)

Separating focusing and elongation

Can be performed by two spatially separated optical elements

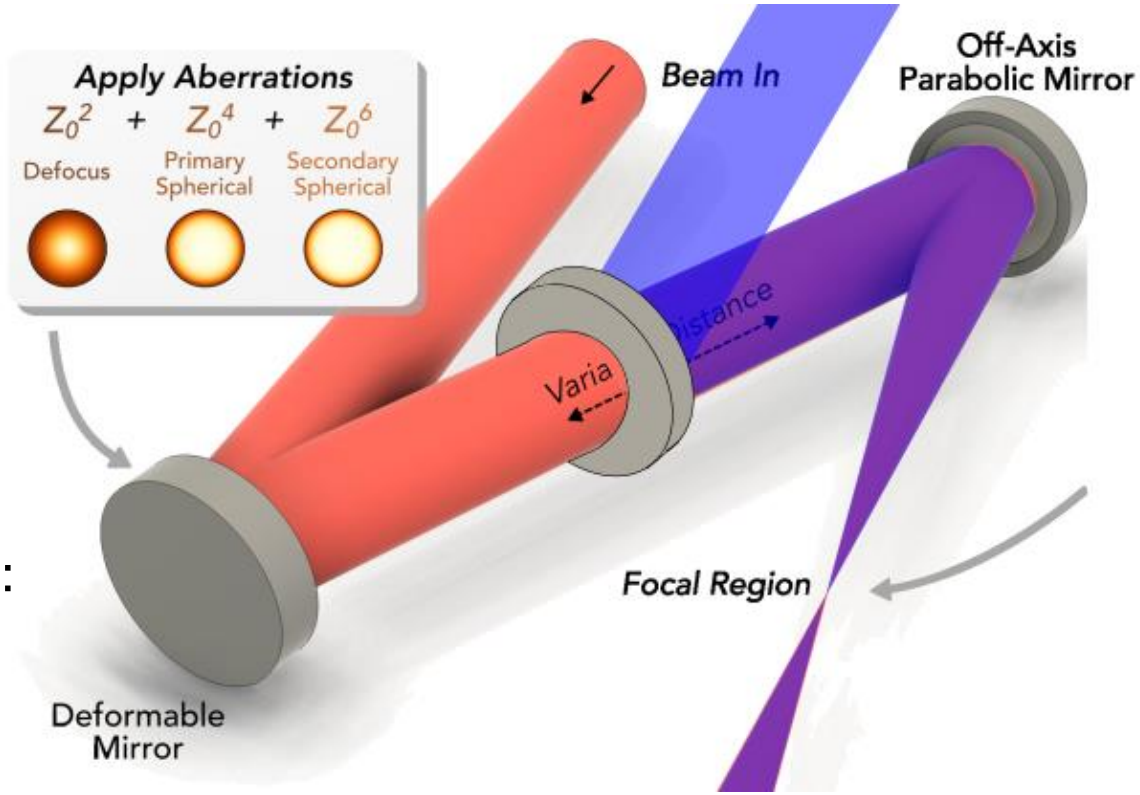
Focusing Phase (OAP)

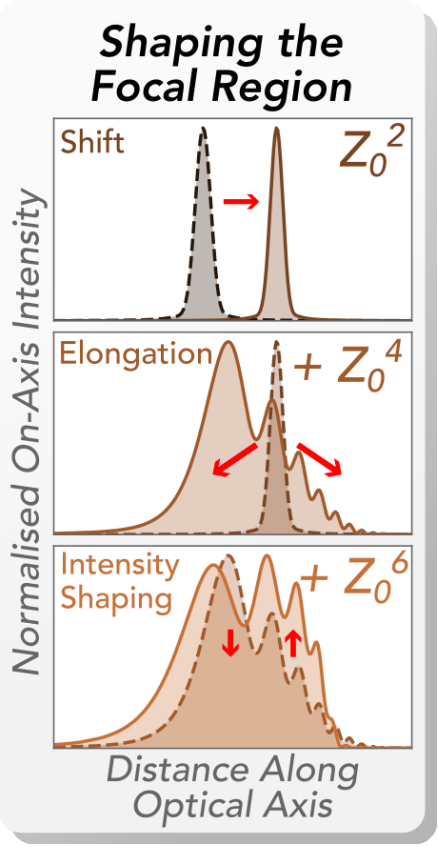
Elongating phase ϕ (DM)

$$\Phi(r) = -\frac{kr^2}{2f_0} + \sum_{n=2,4,\ldots} k\alpha_n Z_n^0\left(\frac{r}{R}\right)$$

Focal position can be analytically calculated:

$$f(r) = \frac{f_0}{1 - \frac{f_0}{kr}\phi'} - \frac{1}{2k}\left(\phi - \frac{r}{2}\phi'\right)$$



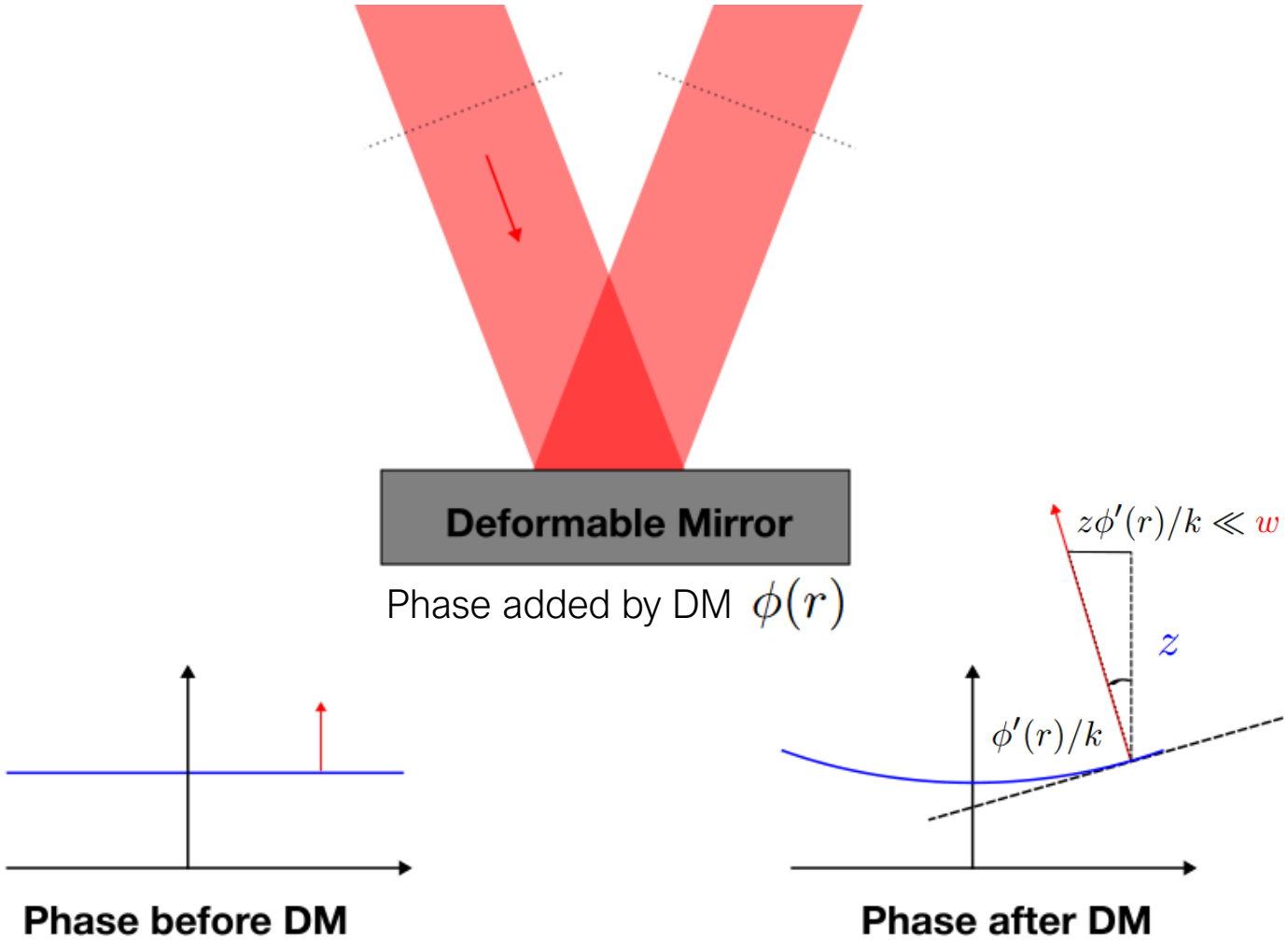


Common focusing optic for channel forming and drive beam can increase stability of guiding

Propagation effects

How far apart can optics be separated

See also:
Poster session Wednesday, LASY: LAsers manipulations made eaSY, Rob Shalloo



Transverse deformation of the beam due to aberrations should be small:

Propagation distance

$$\left| \frac{z\phi'(r)}{wk} \right| \ll 1$$

Laser Beam size

Diffraction effects of unaberrated beam should be small

LASY

[1] Maxence Thévenet et al., arXiv:2403.12191 [physics.optics] (2024)
[2] LASY-org, lasy, GitHub repository, https://github.com/LASY-org/lasy

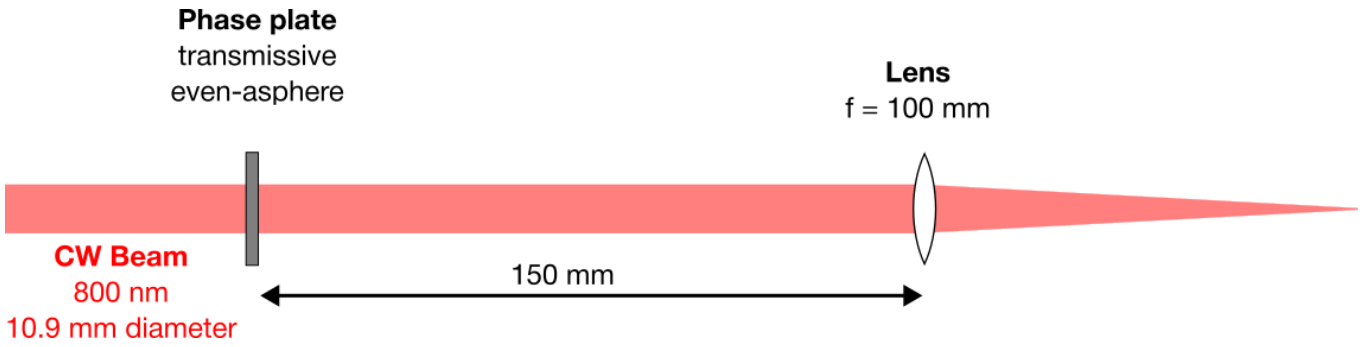
Fixed phase optic for elongation

Demonstration of an elongated focus using two spatially separated optics

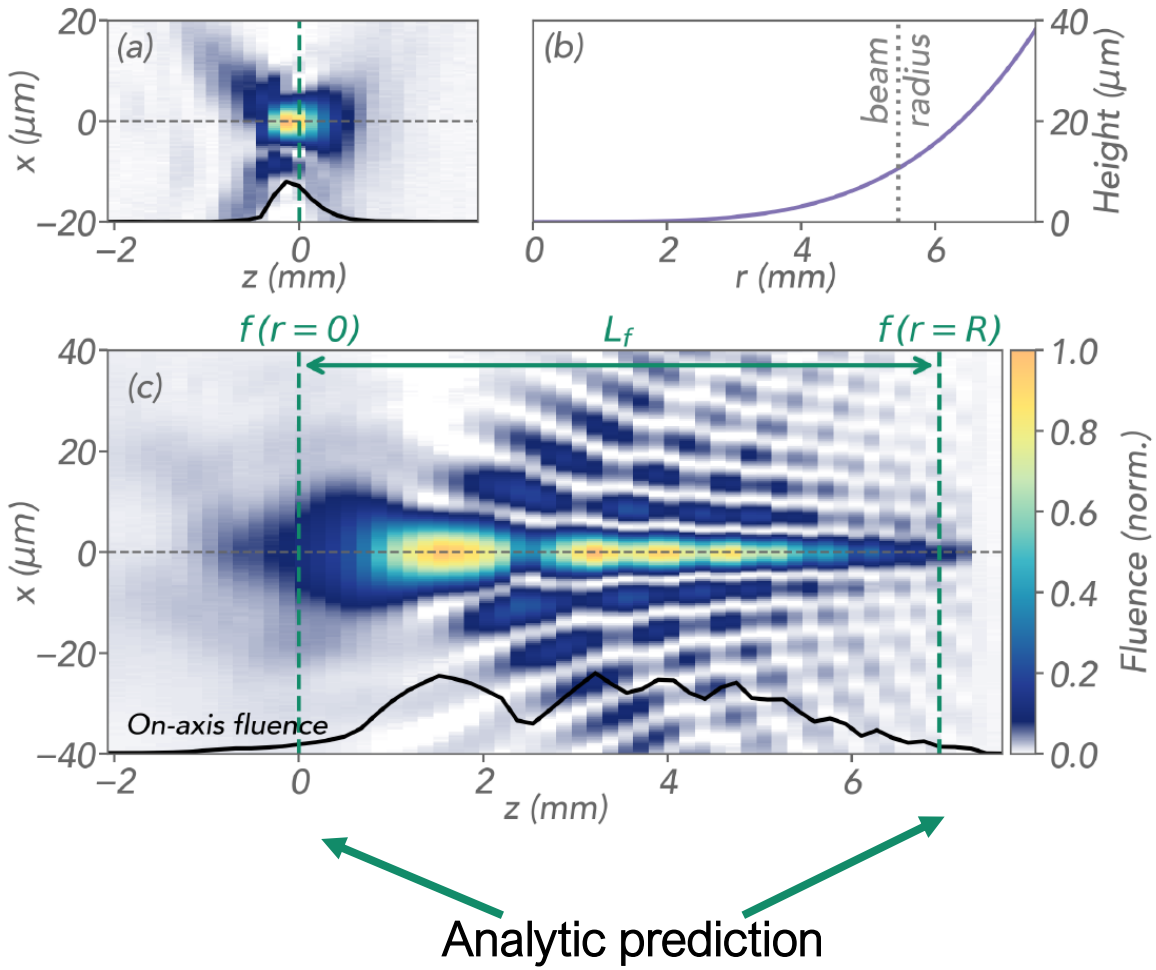
Thin optic, phase deviation of only a few wavelengths

Using a combination of Z_2^0 and Z_4^0 such that $\phi \propto r^4$)

Elongation of focus matching with theory



$$\max\left|\frac{z\phi'(r)}{wk}\right| = 0.1$$



Implementation into an existing LPA

Demonstration of tunable focus elongation using a deformable mirror prior to compression

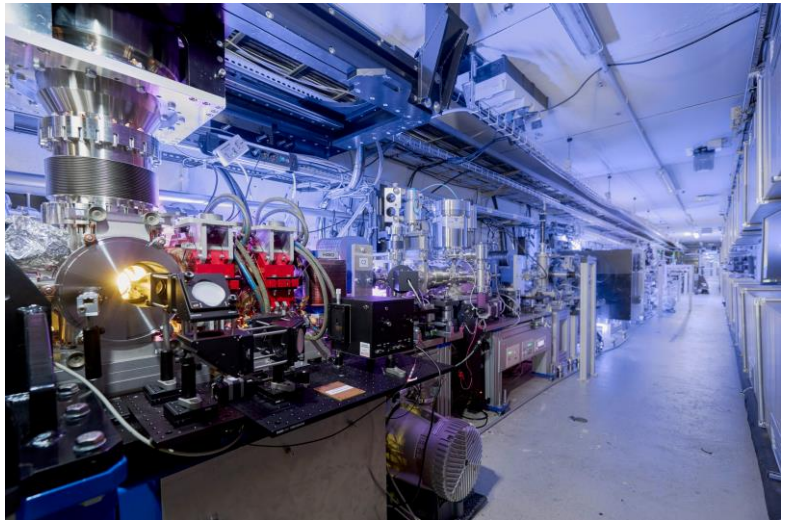
Existing deformable mirror for wavefront flattening prior to final compressor (~34 m before OAP)

- no changes to setup needed

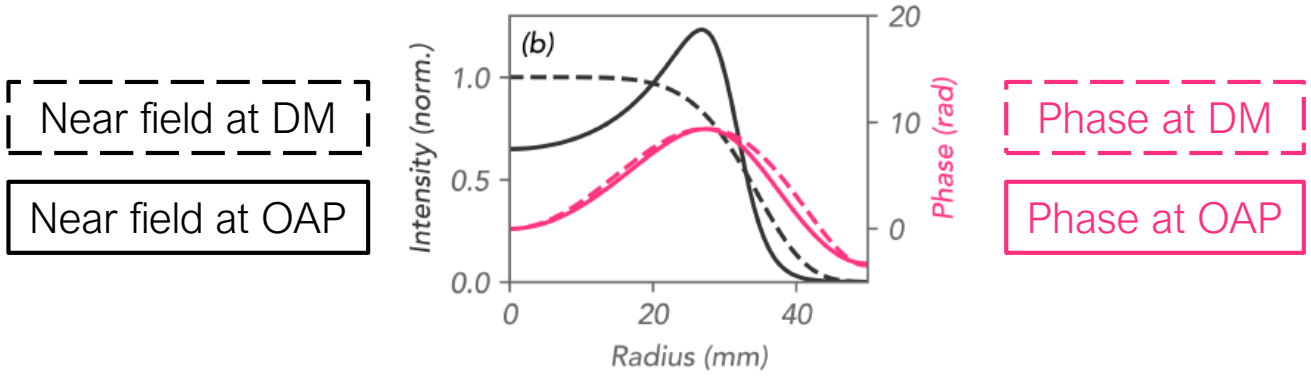
Using DM to add Z_2^0, Z_4^0 and Z_6^0 to elongate and flatten intensity distribution

Simulation of beam transport showed no significant changes in phase profile

LUX accelerator

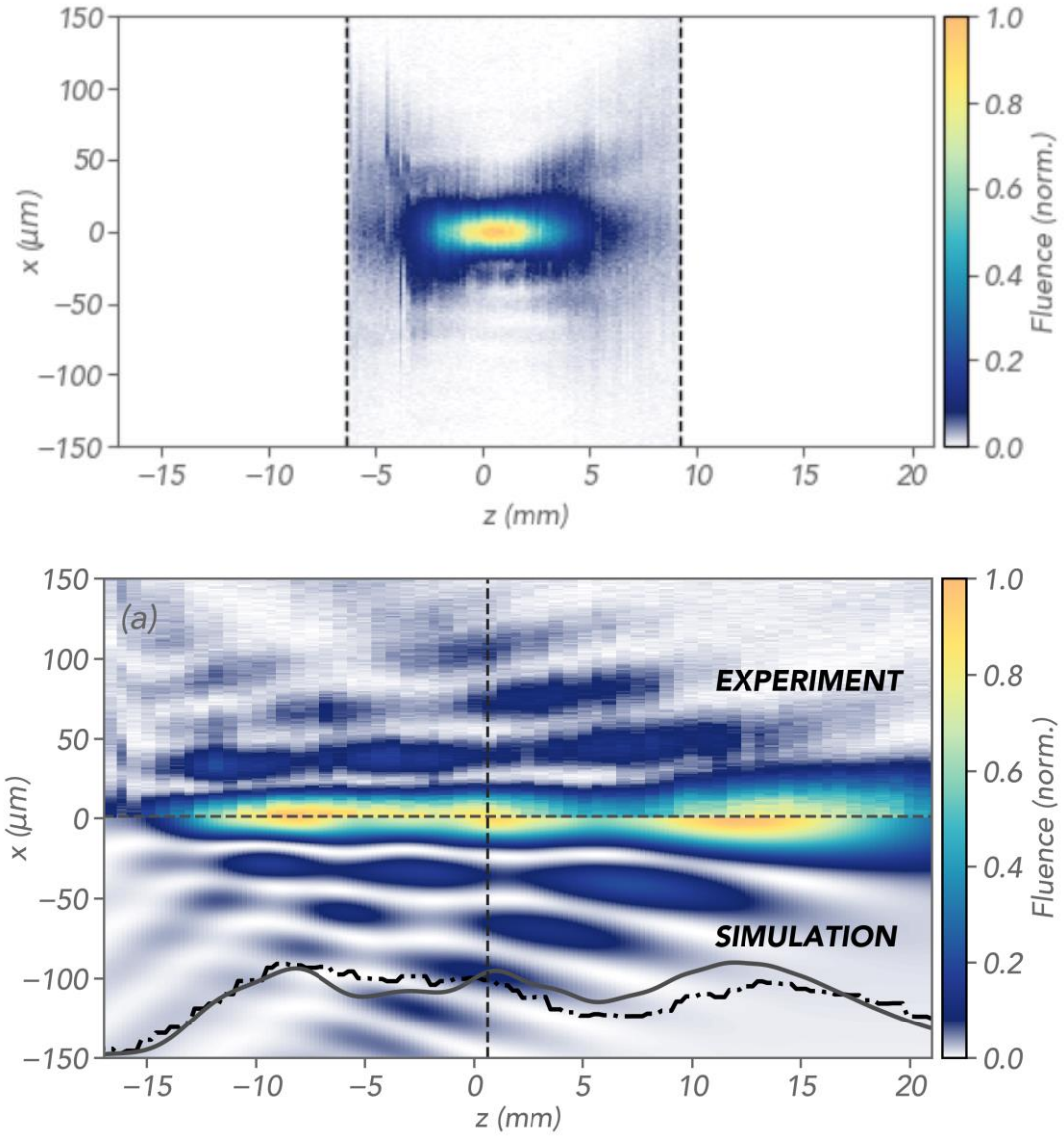


$$\max\left|\frac{z\phi'(r)}{wk}\right| = 0.1$$



Implementation into an existing LPA

Demonstration of tunable focus elongation using a deformable mirror prior to compression



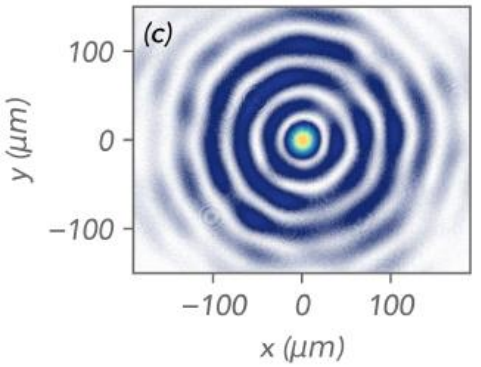
Rayleigh length of unperturbed beam 2.2 mm

Using DM to add Z_2^0, Z_4^0 and Z_6^0 to elongate and flatten intensity distribution

Elongation of focus to > 35 mm length matching with theory/simulations

- Focal length limited by range of focal diagnostic

In-situ tailoring of longitudinal intensity profile



Transverse beam profile

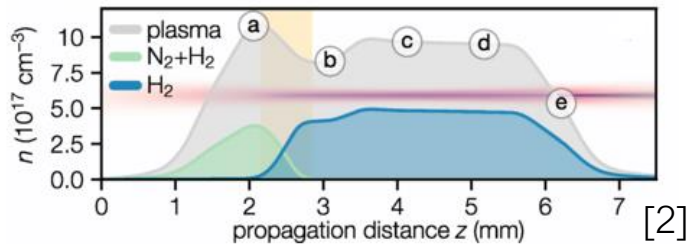
Implementation at DESY

HOFI@MAGMA

See also:
Mo, PS3: Manuel Kirchen – First electrons at KALDERA
Tue, PS7: Soeren Jalas – Data Taking at High Repetition Rate

CDR for PETRA IV plasma injector proposes concept for plasma source:

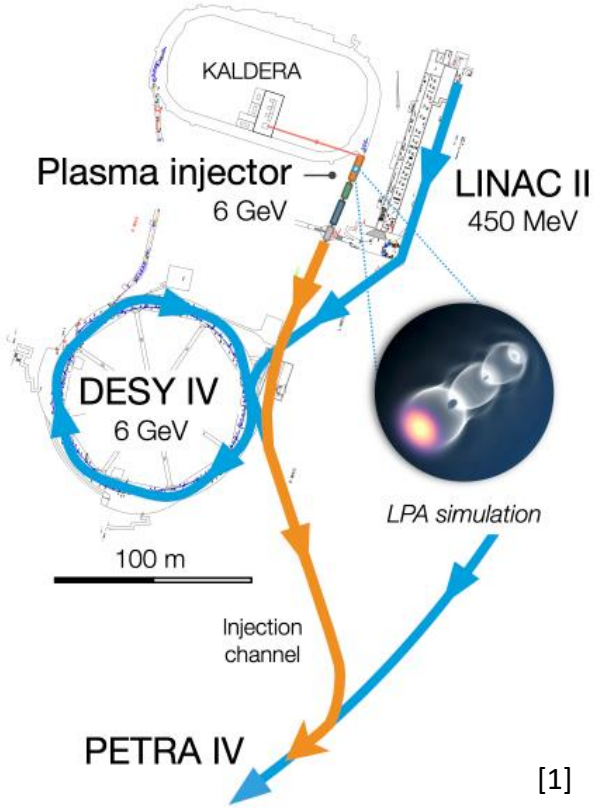
Downramp assisted ionization injection



[2]

+

HOFI plasma waveguiding



[1]

Proof of principle experiments at few hundred MeV level

Could use phase tailoring for elongating the focal region of the channel forming beam

[1] PIP4 Conceptual Design Report, Alberto de la Ossa
[2] M. Kirchen et al., Phys. Rev. Lett. 126, 174801 (2021)

Flexible achromatic flying focus generation

Control over the focal region – not only useful for HOFI

[1] Palastro et al.,Phys. Rev. Lett. 124, 134802 (2020)
[2] Caizergues, et al., Nature Photonics, 14 (8), pp.475-479 (2020)
[3] M. V. Ambat, J. L. Shaw, J. J. Pigeon, et al., Opt. Express 31, 31354 (2023)

Flying focus could be used to overcome dephasing in LPA [1] [2]

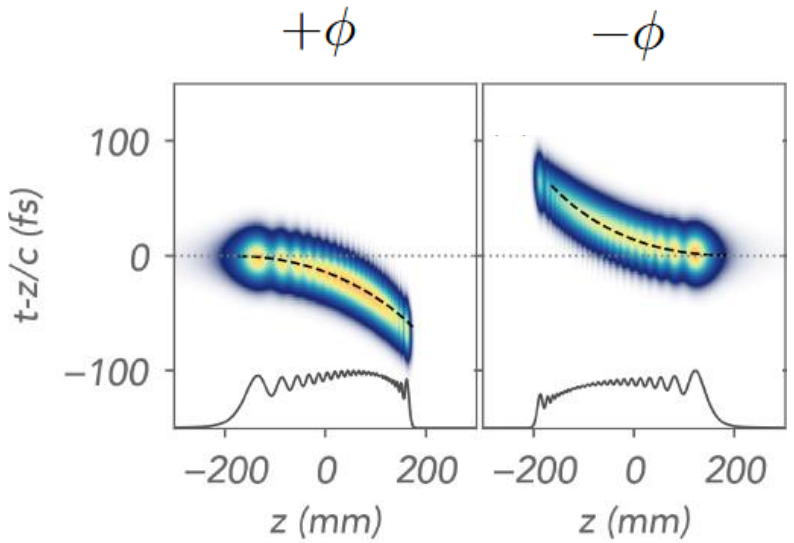
Axiparabola + retardance optic (i.e. echelon)

Could be exchanged by OAP + Deformable Mirror

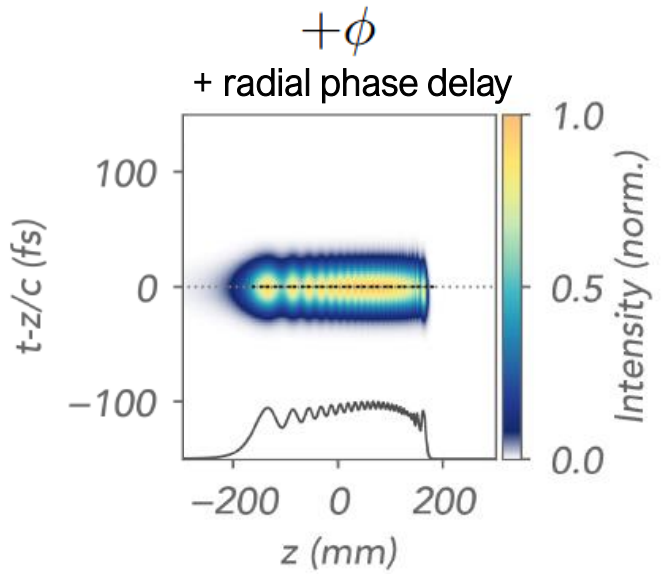
Existing concept for exchanging retardance optic by deformable mirror + spatial light modulator [3]

→ All-adaptive-optic solution possible

800 nm central wl
200 mm diameter Deformable Mirror
20 m propagation
6 m focal length

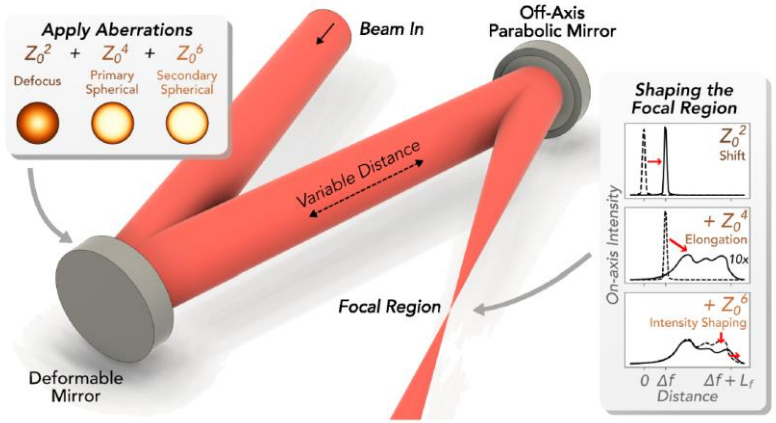


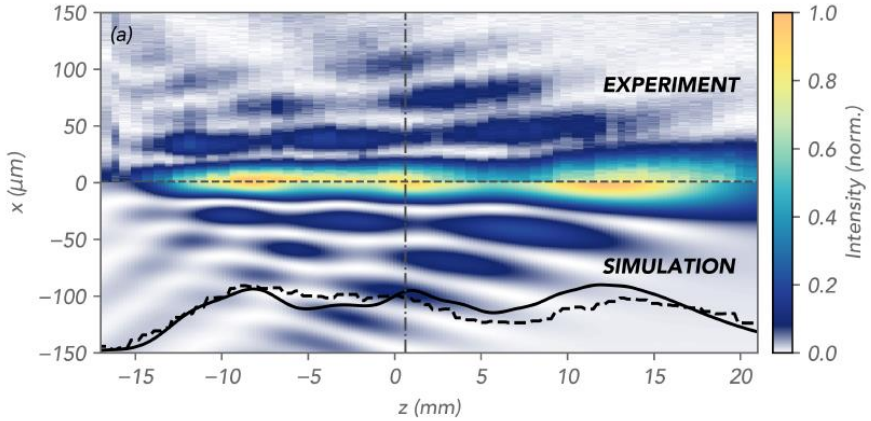
Elongated foci by design are flying foci
→ Further control by retardance optic



Acknowledgements

The Team at *DESY.*





For more information see our paper:
P. Blum, A. Puchert et al., '*Programmable Focal Elongation and Shaping of High-Intensity Laser Pulses using Adaptive Optics*', *submitted*


P. Blum


A. Puchert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